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7.0-1026-7
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NSG 5014

An Investigation of Vegetation and Other Earth
Resource/Feature Parameters Using Landsat and Other Remote
Sensing Data

- A. Landsat
- B. Remote Sensing of Volcanic
Emissions

Semi-Annual Status Report (#10)

January 1 to June 30, 1979

Dartmouth College

Hanover, NH 03755

(E79-10267) AN INVESTIGATION OF VEGETATION
AND OTHER EARTH RESOURCE/FEATURE PARAMETERS
USING LANDSAT AND OTHER REMOTE SENSING DATA. N79-31726
A: LANDSAT. B: REMOTE SENSING OF VOLCANIC H/C A03/MF A01
EMISSIONS Semiannual Status Report, 1 Jan. G3/43 00267
Unclas

Richard E. Stoiber

Researchers:

Emily Bryant

A.G. Dodge, Ken Sutherland (UNH)

Joseph Francica,

John Drexler,

Lawrence Malinconico,

Student Assistants

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Dartmouth College

Semi-Annual Status Report - NSG 5014 - June 30, 1979

This report covers activities of the Landsat Sensing Research Group (Earth Resources) and of the Volcanic Gas Sensing Research Group (Planetary Science) which work in collaboration with the Goddard Institute for Space Studies, New York, Dr. Robert Jastrow, Director. Dr. Stephen Ungar of GLSS is the Technical Officer for this project.

A. Landsat

The Dartmouth Landsat Research Group continued application studies for Landsat data under the general category of analysis of vegetation cover, especially forestry and geobotany, that is, the effects of soil/earth mineral content on vegetation.

1. Agricultural Crop Studies. No research activities in period. (No funds allocated.)
2. Forestry (Emily Bryant). This work includes the effort of Ms. Bryant and her student assistants, in collaboration with A.G. Dodge, Area Forester, Cooperative Extension Service, University of New Hampshire, whose services are furnished under a task order to UNH by Dartmouth.

Ken Sutherland, Assistant County Forester with the Grafton County Extension Service started working on a permanent, half-time basis in January, under the UNH task order.

I. Research

This half year, a continuing theme in our research has

been correction for atmospheric differences from one Landsat pass to another, so that signatures can be extended over time and space. We have also worked on several other projects throughout the six-month period.

Correction for atmospheric differences is an important topic on which much effort has been spent across North America without very many astounding results. We have pursued the topic in hopes that the peculiarities of the terrain types we work with and the information needs of the users we work with are such that we may have some success.

The technique we have been working on is called "fudge factors" and is based on correcting new Landsat data to fit established signatures rather than correcting established signatures to fit new data. We have used this to extend clearcut signatures over time from June, 1975 to June, 1978, as reported in our poster paper given at ERIM. In using the fudge factor technique, we have found that although quantitative comparison of acreage by category from pass to pass is still somewhat shaky, qualitative changes (such as presence of a new clearcut) can be identified quite reliably. We are continuing the investigation into the fudge factor technique, trying different passes and signatures and varying the technique itself to see how the classifications respond.

Other projects that we have been working on are listed below:

1) Forest Fire: We printed out Landsat classifications of 10 townships in a state forest fire district for evaluation by the district chief, John Ricard.

2) Madison: We used the fudge factor technique in mapping the

town of Madison, NH in 1973 and 1978. These experimental runs were done in cooperation with a Resource Conservation and Development Project on forest management within towns. We wanted to see if Landsat classification could be used in practical way to map changes in forest type. Results are still being evaluated.

3) Groveton: We made a Landsat classification to match the type map made by Goveton Papers Company from aerial photos of one of their ownership regions. These signatures are going to be used on an adjacent area and be compared with the Groveton type map. In this project we are aiming to make a final product to meet the needs of the user. This involves locating boundaries and other features on the Landsat printout.

4) Atmosphere: We completed the applications phase of the atmospheric perturbation project which Richard Kiang was working on.

II. Spreading the Word.

A. Papers and Presentations

Poster presentation at the ERIM Symposium on Remote Sensing of Environment, April 24, 1979, entitled, "Small Forest Cuttings Mapped With Satellite Data" (Enclosure 1).

Sent manuscript "Landsat For Practical Forest Type Mapping? A Test Case" to the Journal Photogrammetric Engineering and Remote Sensing. No word on acceptance yet (Enclosure 2).

Gave lecture to UNH remote sensing classes, April 2, 1979.

Gave lecture to Dartmouth Geography Department's remote sensing class, May 22, 1979.

Gave lecture to Dartmouth's Geography "Stretch" class, June 22, 1979.

B. Contacts

Visits to field foresters at Ammonoosuc Ranger District of the U.S. Forest Service, Groveton Papers Company, St. Regis Paper Company, and Brown Company.

Talked with Kurt Olson at UNH about their remote sensing project, which includes computer classification of digitized U-2 photos as well as work with satellite and low-level remote sensing data.

Comments to Assistant Dean of the College of Life Science and Agriculture on Multistage Inventory of Forest Resources Research Project - resulted in approval.

Submitted proposal to NASA/Washington on the "Remote Sensibility" course.

Members of the Vermont Landsat project visited us in January to get a feeling for how Landsat classifications work in this area.

3. Land Use. No research activities in period. (No funds allocated.)

4. Water Quality. No research activities in period. (No funds allocated.)

5. Mineral Resources. Work under this heading is undertaken by Professor Birnie with Graduate Student, Joseph Francica and student assistants.

a) The data processing has continued for the September 1978 experiments at the Mesatchee Creek Prospect (formerly reported as the American River Prospect) in Washington. Professor Birnie and Graduate Student Francica and an undergraduate are working on

this program. A thresholding technique involving a 560nm/460nm intraspectrum band ratio easily discriminates the geobotanical anomaly associated with the mineralized zone. Presentations and manuscripts are being prepared.

b) Discrimination of rock types in the Indus/Tsangpo Suture Zone in the Ladakh Himalaya (India) using Landsat Digital Data is being done at the present time by Joe Francica under the guidance of Professor Birnie and Professor Johnson. Using the GISS Algorithm for rock-type discrimination, geologic maps are being produced. These maps will be used when a field check of the area (NSF grant) is conducted in August and September 1979. Subsequent revisions will be made resulting in a geologic map 200km-250km in length and 50km-100km in width. This area is of significant geologic interest because it is believed to be the zone of collision between the Indian and Eurasian plates during Eocene Time.

c) Professor Birnie and J. Francica have submitted an abstract for a presentation at the GSA Annual Meeting in San Diego, November 1979 (Enclosure 3).

d) Geodynamics of Pakistan, published by the Geological Survey of Pakistan, Quetta, 1979 includes an article "Segmentation of the Quaternary Subduction Zone Under the Baluchistan Region of Pakistan and Iran" by J. Dykstra and R.W. Birnie.

e) Professor Birnie submitted an abstract (Enclosure 4) for a poster presentation at the Gordon Research Conference "Remote Sensing of Earth Surface" in Plymouth, NH, for August, 1979 (unfortunately a family medical emergency prevented Professor

Birnie's attendance but his presentation was handled by Dr. Stephen Ungar of GISS).

B. Remote Sensing of Volcanic Emissions

This work was undertaken by Professor Stoiber, Graduate Students Lawrence Malinconico and John Drexler, Technical Assistant Geoffrey Bratton and student assistants.

1) Lawrence Malinconico went to Kilauea Volcano, Hawaii in June, 1979 partly funded by NASA. He has begun to monitor the SO_2 daily and will continue thru August. He will monitor Mauna Loa at least once. Professor Stoiber will monitor HCl during summer, 1979 if concentrations are high enough. Plans to take samples of condensed gas will be formulated. An abstract of presentation was submitted for the Hawaii Symposium on Intraplate Volcanism and Submarine Volcanism, at Hilo Hawaii, July 16-22, 1979 (Enclosure 5) subject " SO_2 Monitoring by Remote Sensing at Kilauea Volcano, Hawaii".

2) Arrangements have been made to run another set of experiments on sulfur dioxide determination from the air similar to those of February, 1978 (see Enclosure 6, paper presented at Americal Chemical Society Meeting, Honolulu, April, 1979). This will be as before in cooperation with NCAR using the Queenaire in February, 1980.

3) Although the Remotely Piloted Aircraft Project remains inactive because plans to visit, for a field trial, the optimum locality at Masaya, Nicaragua, were cancelled due to extreme political unrest in Nicaragua, there is some hope that conditions will be better this coming year.

4) The HCl instrument (GASPEC) was field tested in Guatemala in May, 1979. The results are still being evaluated (Enclosure 7).

5) A plan to determine the use of Landsat and other space imagery in connection with our overall emphasis on monitoring the world's volcanoes is being prepared as a possible Ph.D. project. This will require ground truth monitoring. A small NSF grant awarded for the purpose in Spring, 1979 will help support this.

6) Preliminary work was undertaken on the study of the use of existing algorithms so that digital Landsat data can be used to identify and outline volcanic plumes. We have had preliminary success. New tapes of plumes are on order.

7) A paper on preliminary Hawaiian Volcano observation results was presented at the 2nd International Colloquium on Mars, Pasadena, California, January 15-18, 1979 (Enclosure 8).

8) A very small amount of NASA support was provided for field work by P. Murrow, a master's candidate in Geology. Her thesis entitled "Cyclical Variation in Historic Eruptions of Mt. Etna, Sicily" was accepted in June, 1979 (copy of Abstract attached, Enclosure 9). An article "Fluctuations in SO₂ Emission During Recent Eruptions of Etna" by Lawrence Malinconico was published in NATURE, Vol. 278, p. 43, 1 March, 1979 (Enclosure 10).

Enclosures 1-10



ENVIRONMENTAL
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TUESDAY

3:30

APRIL 24

POSTER SESSION B

(Michigan League)

- [B1] REAL-TIME VHF DOWNLINK COMMUNICATION SYSTEM FOR SLAR DATA
R. J. Schertler, T. L. Chase, R. A. Mueller, I. Kramarczuk, R. J. Jirberg and R. T. Gedney, NASA/Lewis Research Center, Cleveland, Ohio, USA
- [B2] USEFULNESS OF MODELS FOR PREDICTING ICE FLOES IN BAFFIN BAY
B. Dey and A. F. Gregory, Gregory Geoscience, Ltd., Ottawa, Ontario, Canada
- [B3] AN EVALUATION OF PARAMETRIC AND NON-PARAMETRIC ALGORITHMS FOR UNSUPERVISED CLASSIFICATION OF SURFACE DISTURBED LANDS
Paul Mausel, Leonard Alger and Patrick Madison, Indiana State University, Terre Haute, Indiana, USA
- [B4] LOOKING FOR A PROPER DATA PROCESSING FOR MONITORING HEAT LOSSES FROM ROOFS
Giuseppe Pizzaferrì, Arnaldo M. Tonelli and Claudio Vergani, Rossi-ARCO ent., Milano, Italy
- [B5] AN EVALUATION OF LANDSAT-D FOR CANADIAN APPLICATIONS
A. K. McQuillan and W. M. Strome, Canada Centre for Remote Sensing, Ottawa, Ontario, Canada
- [B6] TEMPORAL STUDY ON PADDY (RICE) USING X-BAND SCATTEROMETER
O. P. N. Cella, N. S. Pillai, O. P. Kaushik and G. Sivaprasad, Space Applications Center, ISRO, Ahmedabad, India
- [B7] SMALL FOREST CUTTINGS MAPPED WITH LANDSAT DIGITAL DATA
Emily Bryant, Arthur G. Dodge, Jr., and Martha Jean Eger, Dartmouth College, Hanover, New Hampshire, USA

- [B8] CARTOGRAPHY WITH COMBINED LANDSAT AND NAVIGATIONAL SATELLITE DATA
Robert K. Vincent and Ronald A. Harrow, GeoSpectra Corp., Ann Arbor, Michigan, USA
- [B9] OIL AND GAS EXPLORATION BY PATTERN RECOGNITION OF LINEAMENT ASSEMBLAGES ASSOCIATED WITH BENDS IN WRENCH FAULTS
Rex Peterson, University of Nebraska, Lincoln, Nebraska, USA
- [B10] ROCK TYPE DISCRIMINATION AND STRUCTURAL ANALYSIS WITH LANDSAT AND SEASAT DATA: SAN RAFAEL SWELL, UTAH
H. E. Stewart, R. G. Blom, M. T. Dally and M. J. Abrams, Jet Propulsion Laboratory, Pasadena, California, USA
- [B11] MAPPING THERMAL INERTIA, SOIL MOISTURE AND EVAPORATION FROM AIRCRAFT DAY AND NIGHT THERMAL DATA
J. Dejae and J. Mégier, Commission of the European Communities, Joint Research Centre, Ispra, Italy
- [B12] "CITHARE"—THERMAL INERTIA AND HUMIDITY CARTOGRAPHY OVER AFRICA BY GEOSTATIONARY SATELLITE
M. Vieillefosse and J. C. Favard, Centre National D'Etudes Spatiales, Toulouse, France
- [B13] THEMATIC ADAPTIVE SPATIAL FILTERING OF LANDSAT LANDUSE CLASSIFICATION RESULTS
Klaus I. Itten and Fritz Fasel, University of Zurich, Zurich, Switzerland
- [B14] LAND USES AND COVER CHANGES IN THE KAINJI RESERVOIR AREA (NIGERIA)
D. Rodriguez-Bajrano and F. E. Okoye, The University of Michigan, Ann Arbor, Michigan, USA
- [B15] MULTISPECTRAL ATMOSPHERIC CORRECTION FOR TIROS-N MEASUREMENTS OF GREAT LAKES SURFACE TEMPERATURE
Jean-Luc Morcrette and George J. Irbe, Atmospheric Environment Service, Downsview, Ontario, Canada

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Submitted for Publication, June, 1979

"Photogrammetric Engineering and Remote Sensing"

Enclosure 2

Landsat for Practical Forest Type Mapping?

A Test Case

Emily Bryant

Arthur G. Dodge, Jr.

Samuel D. Warren

Abstract: In a cooperative project, the Cooperative Landsat Applications Research Group compared computer classified Landsat maps with a recent inventory of forest lands in northern Maine. Over the 196,000 hectare (485,000 acre) area mapped, estimates of acreages of softwood, mixed wood, and hardwood by the two methods agreed to within 5%. In the user's opinion, these results are promising enough to warrant further development of the techniques so that computer classification of Landsat data can be included in practical forest inventory systems. We distinguish this from other Landsat forestry projects because:

- The user is involved.
- Ground truth is from an existing inventory and therefore represents real operational information needs.
- The individual geographic units mapped are relatively small and have user-defined boundaries.
- Results are from an applications area.

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ABSTRACT FORM

Exact format shown on instruction sheet must be followed.

REMOTE DETECTION OF GEOBOTANICAL ANOMALIES: A METHOD FOR MINERAL EXPLORATION

BIRNIE, Richard W.; FRANCICA, Joseph R. Jr.;
Dept. Earth Sciences, Dartmouth College,
Hanover, NH 03755

Visible and near infrared (450-1000nm) reflected radiance spectra of Douglas Fir trees were measured at the American River porphyry copper prospect in western Washington State. These measurements were made with an airborne spectrometer with a 18m spacial resolution and a 1.4nm spectral resolution. Analysis of the spectral data indicates that the vegetation growing within the pyrite halo of the copper deposit has anomalously high reflected radiance values at 560nm. At 460nm, the mineralized and nonmineralized spectra show no difference. Six flight lines were flown on each of two days. Taking one flight line from the first day's data as the control line, individual spectra with a 560nm/460nm reflected radiance ratio value greater than 1.7 cluster within the pyrite halo. When this threshold value is applied to all flight lines on the first day, 37% of the spectra within the pyrite halo and 5% of the spectra outside the pyrite halo are classified as anomalous. The zone of mineralization is clearly defined by the cluster of anomalous spectra. There is an 87% probability of an anomalous spectrum lying within the mineralized zone. The same technique was applied to the second day's data. The threshold was optimized at 1.6 and the resultant probability of an anomalous spectrum lying within the mineralized zone is then 93%.

CLASSIFICATION

You must specify one. If more than one category is appropriate, indicate your order of preference by numbers. Be specific.

archaeological geology

coal geology

X economic geology

engineering geology

extraterrestrial geology

general geology

geochemistry

geology education

geomorphology

geophysics

geoscience information

history of geology

hydrogeology

marine geology

mathematical geology

mineralogy/crystallography

paleontology/paleobotany

petrology

experimental

igneous

metamorphic

Precambrian geology

Quaternary geology

sedimentology

sedimentary petrology

stratigraphy

structural geology

tectonics

volcanology

OTHER

☐ Oral ☐ Poster ☒ EitherORIGINAL PAGE IS
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(title of symposium for which abstract was invited)

PLEASE NOTE: All invited symposium abstracts (original plus two copies) must be sent to the organizers of the respective symposia according to deadlines established by symposium organizers.

Speaker Richard W. BirnieGSA Member ☒GSA Student Associate ☐Member of Society Associated with GSA ☐ WhichNonmember ☐I will be available to serve as a cochairman for a technical session on or concerning Remote Sensing

For correspondence purposes, list address of speaker if different from above

Phone numbers and dates where speaker can be contacted (603) 646-2666 (at all times).

REMOTE DETECTION OF STRESSED VEGETATION:

A METHOD FOR MINERAL EXPLORATION

Visible and near infrared (450-1000nm) reflected radiance spectra of Douglas Fir trees were measured at the American River porphyry copper prospect in western Washington State. These measurements were made with an airborne spectrometer with a 18m spatial resolution and a 1.4nm spectral resolution. Analysis of the spectral data indicates that the vegetation growing within the pyrite halo of the copper deposit has anomalously high reflected radiance values at 560nm. At 460nm, the mineralized and nonmineralized spectra show no difference. Six flight lines were flown on each of two days. Taking one flight line from the first day's data as the control line, individual spectra with a 560nm/460nm reflected radiance ratio value greater than 1.7 cluster within the pyrite halo. When this threshold value is applied to all flight lines on the first day, 37% of the spectra within the pyrite halo and 5% of the spectra outside the pyrite halo are classified as anomalous. The zone of mineralization is clearly defined by the cluster of anomalous spectra. There is an 87% probability of an anomalous spectrum lying within the mineralized zone. The same technique was applied to the second day's data. The threshold was optimized at 1.6 and the resultant probability of an anomalous spectrum lying within the mineralized zone is then 93%.

Gordon Research Conference:

Remote Sensing of Earth's Surface

Aug 20-24, 1979

Plymouth, N.H.

Second Circular

Hawaii Symposium on Intraplate Volcanism and Submarine Volcanism



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HILO, HAWAII
JULY 16-22, 1979

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SO₂ Monitoring by Remote Sensing at Kilauea Volcano, Hawaii

Richard E. Stoiber

Lawrence L. Malinconico, Jr. (both at: Dept. of Earth
Sciences, Dartmouth College, Hanover, NH 03755)

The SO₂ mass flow from Kilauea Volcano during the period 3 to 7 October, 1978 averaged 220 metric tons per day.

The SO₂ emission was monitored using a remote sensing correlation spectrometer, which operates by measuring the amount of absorption by SO₂ molecules at specific wavelengths in the ultraviolet. The instrument was used in the mobile mode; mounted in a vehicle with a right angle mirror attached to the telescope and then driven under the plume. The values obtained are considered minimums, as the spectrometer is a pathlength dependent device and is susceptible to scattering and dilution of the absorption signal. Also, any SO₂ oxidized to other sulfur species or dissolved in water is effectively lost to the spectrometer.

Twenty-two traverses were made during the five day period of the investigation. Traverses were also made completely around the crater and down the Chain of Craters road. This showed the Kilauea crater was the only detectable source of SO₂ within the measuring area. The volcano was in a "quiet" state of activity at the time, with no effusive lava and only gas being emitted from fumaroles in the crater.

Over a six day period in February, 1975 an average of 280 metric tons per day of SO₂ was measured by Stoiber and Malone. In February, 1975 and October, 1978 the volcano was in a state of quiescence so it seems reasonable to assign an average emission level of 200 to 400 metric tons of SO₂ gas per day to a quiescent Kilauea.

The implications of this output relative to degassing of subsurface magma is examined and the ratio of other gases to SO₂ are used to estimate daily output of other gases.

SO₂ measurements from other volcanoes suggests that the SO₂ emission levels reflect the activity of the volcano. A similar situation should exist at Kilauea, and monitoring variations in the mass flow of SO₂ might even provide short term premonitory signs of activity.

Not For Publication

Presented-Before the Division of Environmental Chemistry
American-Chemical-Society
Honolulu, Hawaii, April 1-6, 1979

AEROSOL PRECURSORS AND AEROSOLS EMITTED
TO THE ATMOSPHERE BY EXPLOSIVE VOLCANOES

R. D. Cadle¹, W. I. Rose², A. L. Lazrus¹
B. J. Huebert¹, R. Stoiber³, and R. L. Chuan⁴

¹National Center for Atmospheric Research*, Boulder, CO 80527

²Michigan Technological University, Houghton, MI 49931

³Dartmouth College, Hanover, NH 03755

⁴1457 E. Altadena Drive, Altadena, CA 91001

Violent explosive eruptions of volcanoes inject huge quantities of particles and sulfur-containing gases that become particles into the troposphere and stratosphere. The material erupted into the troposphere may cause great damage locally, and that injected into the stratosphere may have a significant effect on the earth's surface temperature and modify stratospheric chemistry (1). Most of the emissions into the troposphere have "e-folding" residence times of a few days to a week or two, but fine ash and sulfur compounds may have residence times in the stratosphere for months to a year or more. During the last two decades eruptions by several volcanoes have produced eruption clouds that have penetrated into the stratosphere. Eruptions by Agung in Bali in 1963 and of Vulcan Fuego in 1974 were especially violent.

The particulate material in explosive eruption clouds consists largely of volcanic ash (that is, finely divided lava) and droplets of impure sulfuric acid. However, most of our knowledge of the nature of this material has been based on studies of ash deposits on the ground, although limited studies of collected ash have been made from aircraft (for example, Cadle *et al.* (2) and Hobbs *et al.* (3)). The determination of the gaseous emissions from explosive volcanoes have been limited to emissions from fumaroles and from craters between explosive eruptions.

In order to obtain more direct information concerning the composition of eruption clouds from explosive volcanoes, during February, 1978, a group of scientists from the National Center for Atmospheric Research, several colleges and universities, the USGS, and NASA used a specially-equipped Queen Air aircraft to make eleven sampling flights through the eruption clouds from the volcanoes Pacaya, Fuego, and Santiaguito in Guatemala. During our sampling, Pacaya was in a state of intense vapor emission and when vapor emission abated, glowing magma could be observed through gashes within McKenny crater. During February, Fuego underwent mild vulcanian eruptions producing substantial amounts of ash which were interspersed with vaporous ash-poor plumes. Both types of eruption clouds were sampled. Santiaguito is a Peléean dome which produced several pyroclastic eruptions each day, some reaching several kilometers above the top of the dome.

*The National Center for Atmospheric Research is sponsored by the National Science Foundation.

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Aerosol particles were collected with two impactors, one a ten-stage piezo-electric device mounted on the aircraft wing to provide size distributions, scanning electron micrographs (SEM), and EDXRA results (4, 5). The other was a single stage device for transmission electron micrographs (TEM), SEM, and EDXRA.

Rates of emission from the volcanoes of sulfur dioxide were determined with a correlation spectrometer and wind velocity data obtained with the plane's inertial navigation system. Sulfate and sulfur dioxide in the eruption clouds were collected simultaneously along with other substances such as particulate and gaseous chlorine-containing compounds with non-impregnated "fluoropore" filters and Whatman filters impregnated with an organic base. The filters were mounted in series. Extracts of the filters were analyzed colorimetrically. The "fluoropore" filters collected particulate material and the impregnated "Whatman" filters collected acid gases. Samples were also collected in stainless steel canisters for subsequent gas chromatographic analysis (6).

The rates of emission of SO_2 were estimated to vary from hundreds to about one thousand tons per day from each of the volcanoes. Considering the number of volcanoes that are erupting on the average over many years, these figures are not out of line with estimates of average world-wide SO_2 emissions by erupting volcanoes (7).

The concentrations of SO_2 always greatly exceeded that of sulfate, which judging from the electron micrographs and previous work at volcanoes was largely in the form of sulfuric acid. The lowest $[\text{SO}_2]/[\text{H}_2\text{SO}_4]$ volume concentration ratio was about 9. This was true even for the large Santiaguito eruptions where much of the SO_2 might have been oxidized and hydrated to form sulfuric acid in the eruption clouds. An implication of this result is that so much SO_2 enters the atmosphere from a huge eruption such as that of Agung in 1963 that the OH concentration of the stratosphere is markedly depleted of OH by reaction with SO_2 , thus greatly slowing for many months the formation of sulfuric acid. In fact, the particulate chloride concentrations often exceeded the sulfate concentrations.

Size distributions were plotted as a function of the total mass of particles collected on each impactor stage vs the 50% cut-off diameter for each stage assuming a particle density of 2.0 g/cm^3 . The cut-off diameters of the ten stages varied from a maximum of $25 \mu\text{m}$, each one-half of the preceding one. The size distributions plotted in this manner were invariably bi- or trimodal. Surprisingly large mass concentrations were often found on the last three stages (smallest cut-off diameters). These particles consisted of impure sulfuric acid droplets, finely divided glassy lava, and crystals which had been in the magma. A magma which contains a large percentage of small crystals may produce smaller ash particles (which will remain in the air for a long time) than an essentially non-crystalline magma.

The sources of atmospheric carbonyl sulfide (COS) are of interest with regard to the particulate content of the atmosphere, especially of the stratosphere, because of a recent suggestion

that COS is the main source of sulfuric acid droplets in the stratosphere during periods when there is little extremely explosive volcanic activity. COS has a very long, perhaps twenty year, tropospheric residence time (8). COS and CO₂ concentrations along with concentrations of a number of other compounds were measured of the gases in the canisters. Some of the COS was lost by adsorption on the canister walls, but a calculation based on the largest [COS]/[CO₂] ratio, corrected for the concentrations in the unperturbed atmosphere, suggested that at most about 10% of the COS in the atmosphere is of volcanic origin. However, additional measurements are needed in which wall losses are avoided.

A two dimensional dynamic model of the transport of tracers in the stratosphere has been applied to the global scale dispersion of the volcanic clouds injected into the stratosphere by violent eruptions (9, 10). The model does not include chemical reactions, and predicts the dispersion of only that ash which is sufficiently fine that its settling rate can be neglected. The results of the work described here demonstrate that refinements of such a model should include the conversion of SO₂ to H₂SO₄ droplets, which may require a year for nearly complete conversion, and the crystallinity of the erupted magma.

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- (1) Cadle, R. D., Grams, G. W., Rev. Geophys. Space Phys., 13, 475 (1975).
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- (3) Hobbs, M. V., Radke, L. F., Stith, J. L., Science, 195, 871 (1977).
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- (5) Rose, W. I., Jr., Chuan, R. L., Cadle, R. D., and Woods, E. C., submitted to Am. J. Sci.
- (6) Rose, W. I., Cadle, R. D., Heidt, L., Friedman, I., Lazrus, A. L., and Huebert, B., submitted to the Journal of Volcanology and Geothermal Research.
- (7) Cadle, R. D., J. Geophys. Res., 80, 1650 (1975).
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NSG 5014


June 8, 1979

Trip Report
Guatemala
May 1979

Richard E. Stoiber with the aid of John Drexler (graduate research assistant on the grant) visited Guatemala May 15 to May 24 to determine whether the HCL remote sensor could detect HCL at volcanoes. Before leaving on the trip laboratory trials and field trials using poorly simulated volcanic conditions had indicated it was operating effectively. Calibration of the instrument was not completed before the trip.

Pacaya and Santiaguito volcanoes were visited with the Gaspec and HCL was detected in the plumes at both volcanoes. Results of preliminary calibration suggest that the machine will detect 400 ppm.m or better. The path thru the plume at Pacaya probably had over 50,000 ppm.m HCL and at Santiaguito probably over 10,000 ppm.m HCL. Careful calibration will be required before these figures can be substantiated. The data at this time cannot be reduced to yield metric tons per day HCL, but there is a strong suggestion that HCL emission may be at least an order of magnitude larger than SO₂. A "best guess" from other volcanologic evidence would have been that HCL emitted at a volcano is equal or only a few times (not 10X) greater than SO₂.

(The trip was also a field trip for graduate students. Hence, most of the expense (including airfare) was born by the instructional budget of the Earth Sciences Department. Excess jeep transportation and portering were required because we were carrying the remote sensing gear and visiting the particular points where the measurements were taken. This was a charge to the grant but amounted to only \$223.87. \$600 had been budgeted.)


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cc Mrs. Wiseman
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File

TERRESTRIAL VOLCANIC DEGASSING:
A REVIEW OF MECHANISMS AND MAGNITUDES

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The magnitudes of the contributions made by degassing of subaerial volcanoes to the terrestrial volatile budget are fairly well understood. These estimates are based largely on the study of subaerial volcanoes which represent only 20 to 25% of total terrestrial volcanism.¹ The 75 to 80% of terrestrial volcanic products from submarine activity probably degas less efficiently than subaerial volcanic products.^{2 3 4} For subaerial volcanic eruptions, degassing of magma occurs during four eruptive or post-eruptive processes: 1) vesiculation during effusion;⁵ 2) explosive eruption;⁶ 3) shallow intrusion of magma within the volcanic edifice; and 4) weathering. These four processes produce different proportions of juvenile gases, depending on the chemistry and plate tectonic setting of the volcanic activity.

For the quiescent period in Hawaii from July -October 1978, we have estimates for the annual production of SO₂ from COSPEC measurements (Stoiber and Malinconico, 1978, unpub. data), and analyses of gases (LeGuern and Casadevall, 1978, unpub. data) and condensates for selected fumaroles. The latter measurements allow the total annual flux of Cl and CO₂ from Kilauea and Mauna Loa to be

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calculated by ratio to SO_2 . Data from sea floor basalts⁷ on the concentration of juvenile water in Hawaiian lavas give an indication of the annual contribution of water to the atmosphere by Hawaiian volcanoes (table).

Taken together, these data provide a relatively complete volatile budget for outgassing of Kilauea and Mauna Loa volcanoes. With the appropriate qualifications, this budget can be useful in assessing the impact of volcanic degassing on the atmosphere and surface geology of Mars.

Part 3 Volatile Production (Metric Tons Per Year $\times 10^5$)

| | SO_2 | $\text{Cl}^{(2)}$ | $\text{CO}_2^{(b)}$ | H_2O | Lava Production Rate |
|--|---------------|-------------------|---------------------|----------------------|------------------------------|
| Hawaii (a) (Kilauea & Mauna Loa) | 0.8 | 0.24-1.2 | 0.5-1.1 | 1 | $0.1 \text{ km}^3/\text{yr}$ |

Extrapolation (c)

| | | | | | |
|---|----|--------|--------|-----|--|
| of Hawaiian volatile production to global production | 80 | 24-120 | 50-100 | --- | |
|---|----|--------|--------|-----|--|

Estimate of total
annual production
due to volcanism

| | | | | |
|--------------------|--------------------------------------|--------------------|----|---|
| 100 ⁽⁸⁾ | 32 ⁽⁴⁾ -70 ⁽²⁾ | 400 ⁽⁹⁾ | -- | 1-1.5 km^3/yr (subaerial) ⁽¹⁾ |
| | | | | 6-8 km^3/yr (submarine) ⁽¹⁾ |

(a) Hawaiian gas analyses made during February 1975, August 1978, and October 1978 during periods of quiescence at both Mauna Loa and Kilauea.

(b) assumes $\text{CO}_2/\text{SO}_2 = 1-2$; $\text{Cl}/\text{SO}_4 = 0.2-1$ (i.e. $\text{Cl}/\text{SO}_2 = 0.3-1.5$)

(c) values for Hawaii multiplied by estimated number (100) of active volcanoes.

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CYCLICAL VARIATION
IN HISTORIC ERUPTIONS
FROM MOUNT ETNA, SICILY

A Thesis
Submitted to the Faculty
in partial fulfilment of the requirements for the
degree
Master of Arts

by
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DARTMOUTH COLLEGE
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ABSTRACT

Eruptive activity on Mount Etna is shown to be cyclic during the last seven hundred years. Three cycles are identified on the basis of characteristic repose times between lava producing eruptions. These are 1284-1533, 1533-1763, 1763-present. Each cycle can be subdivided into periods of high and low magma output rates, about 140 and 90 years long respectively. The high volume phase culminates in a major collapse of the summit area of the volcano. Chemical composition with respect to the major oxides shows a relationship to the proposed cycles. The lavas tend to show trends of increasing and decreasing differentiation which is considered to be related to input of primitive magma from the mantle into a shallow reservoir. The relationship of eruptive vents and summit craters to the reservoir and conduit system is investigated with respect to observations made during the August 1977 eruption of Mount Etna. This study may indicate that Mount Etna is nearing a period of highly voluminous lavas which will continue for approximately 140 years and culminate in a collapse event.

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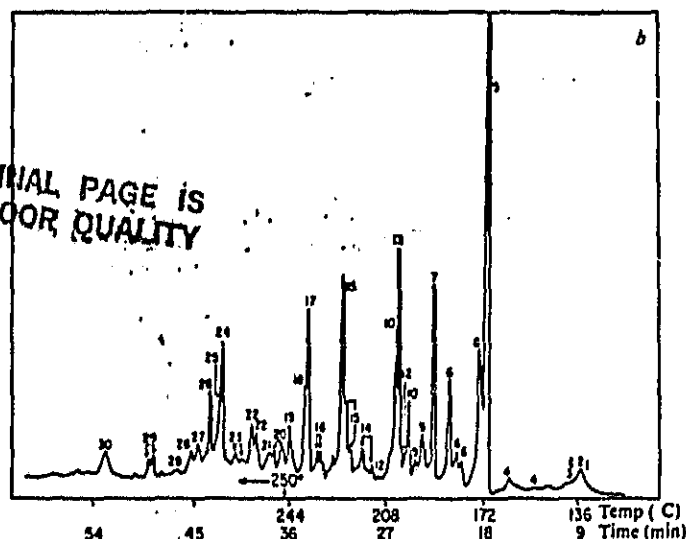
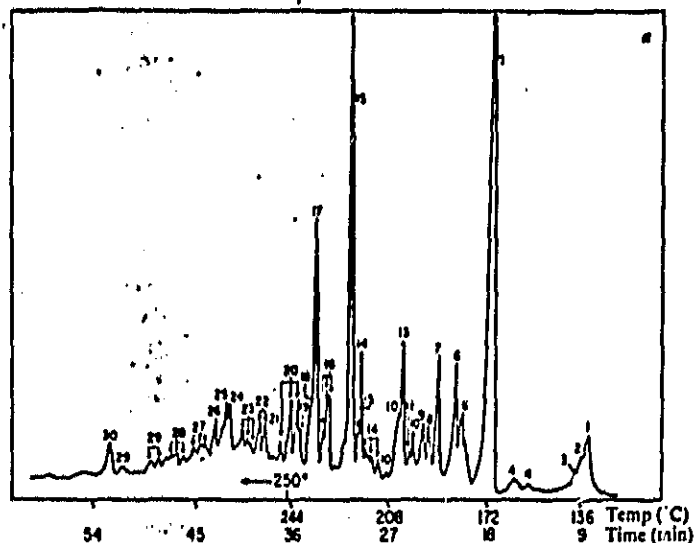


Fig. 1 Gas chromatogram of methyl esters of the organic acid fraction from lignite (a) and from bituminous coal (b). The analysis was carried out on a Perkin-Elmer 3920B gas chromatograph interfaced to a modified Bendix model 12 time-of-flight mass spectrometer with a variable split between a flame ionisation detector and the source of the mass spectrometer. The separation was made on a 15.2 m \times 0.51 mm SCOT column coated with OV17 and temperature programmed from 100–250°C at 4°C min⁻¹.

derived from non-lignin or extensively transformed lignin polymers. It is obvious that extensive transformation of lignin-like polymers occurred through several reactions^{22,23} such as demethylation, demethoxylation, dehydrogenation, oxidation, cleavage of ring structures and re-condensation during coalification from lignite to bituminous and anthracite coals. Indeed, we have observed that the CuO-NaOH oxidation of higher rank coals (C, 78–87%) produces very little phenolic acid with an increased yield of non-hydroxy aromatic and heterocyclic acids (data not shown).

Previously²⁰ we characterised aromatic acids trapped in lignite coal, and have found that these acids are qualitatively quite similar to those obtained from the present oxidation of the same pretreated coal. This indicates that the trapped acids were derived mainly from the hydrolytic oxidative degradation of lignin-like polymers during the coalification. Indeed, the later coalification product, the anthracite coal, did not give any trapped acid²⁰ or organic solvent-soluble CuO-NaOH oxidation product. Flaig has also discussed²² oxidative transformation of plant material during humification and coalification.

Our results show that lignin-like polymers are incorporated into the macromolecules of lignite and bituminous coals. It is indicated that the polymers contain more highly cross-linked structures with increased aromaticity compared with the original lignins. This is experimentally shown by the identification of phenolic polycarboxylic acids and hydroxynaphthalene-carboxylic acids which are not found in the CuO-NaOH oxidation products of lignins and plant materials. In addition, plant polyphenols other than lignin could also be precursors for coal formation.

This work was supported by the Division of Basic Energy Sciences of the Department of Energy.

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Fluctuations in SO₂ emission during recent eruptions of Etna

THE eruptive activity of July–August 1977 of Mt Etna consisted of four separate, short eruptive episodes: 16–22 July; 5–6 August; 14 August; 24 August. The rate of SO₂ emission during these eruptions was monitored using a remote-sensing correlation spectrometer. These data suggest that fluctuations in the SO₂ emission rate provide a means for predicting eruptions of Etna.

The July–August 1977 eruptions were confined to the North East Crater vent, while continuous degassing occurred from the central vents. The continuous gas plume was blown downwind immediately after it was emitted while the eruption plumes from the North East Crater rose 500–1,000 m before being blown horizontally. As the plumes moved downwind they were maintained at elevations ranging from 2,000 to 3,000 m above sea level. Monitoring began on 24 July, immediately after the first eruptive episode had ended, and continued until 27 August.

A Barringer Correlation Spectrometer (COSPEC) was used to monitor the SO₂ in the volcanic plume. (The application and design principles have been described by Newcomb and Millán¹.) The spectrometer consists of a Cassegrain telescope, a

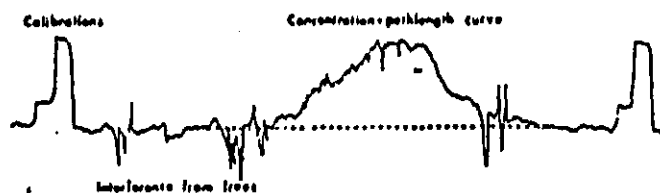


Fig. 1 A typical SO_2 plume cross-section obtained with the COSPEC mounted in an automobile. The instrument is calibrated at both ends of a traverse. The large calibration represents 370 p.p.m. m while the small calibration represents 125 p.p.m. m. The abscissa of the curve is time. A single traverse took ~ 15 min.

grating spectrometer, a correlator disk, and processing electronics section. Incoming radiation is dispersed by the spectrometer. The correlator disk then alternately passes UV spectra of high and low SO_2 absorption. This modulated signal is monitored by photomultiplier tubes which produce a voltage that is processed by the electronics. This processed voltage is proportional to the number of SO_2 molecules in the field of view of the instrument. This is a concentration-pathlength value and has dimensions in parts per million metres (p.p.m. m). The response of the instrument is calibrated by reference cells filled with known concentrations of SO_2 . The instrument also has an automatic gain control to compensate for changes in the radiation source (the daytime sky).

Data reported here were gathered with the COSPEC mounted in a vehicle with a right angle mirror attached to the telescope to allow a vertical field of view. The vehicle was driven under the plume approximately perpendicular to the plume direction. Concentration-pathlength data from the COSPEC are recorded on a stripchart recorder along with odometer readings to provide a distance scale. Instrument calibrations were done before and after each traverse so that instrument drift could be checked. Figure 1 shows the record from a single traverse.

The area under the concentration-pathlength-distance curve represents a SO_2 cross-section of the plume (p.p.m. m^2). This value is corrected for traverses that are not at right angles to the plume direction. A mass flow of SO_2 (tonnes d^{-1}) is calculated by multiplying the p.p.m. m^2 value times the horizontal wind speed of the plume (m d^{-1}) times the density of SO_2 gas (tonnes per p.p.m. m^3).

The traverses were made on the roads shown on Fig. 2. The arrow from the summit shows the average wind direction for the period of this study, while the range of the wind direction

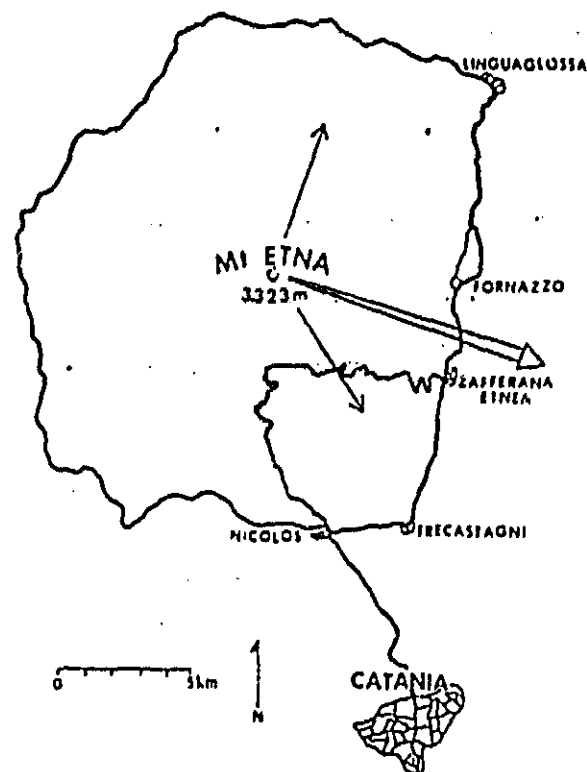


Fig. 2 Map of the roads used to obtain traverse data. The large arrow from the summit represents the mean wind direction while the smaller arrows represent the range of the wind directions.

for the period 16 July–28 August 1977 is shown by the shorter arrows. The roads are all between 7 and 10 km from the summit, and between 1,000 to 2,000 m below the plume as it passed overhead.

Two to eight traverses were made per day. A mass flow value was calculated for each traverse and the values from a given day were averaged to give a mean mass flow value for that day. Cloudy weather (clouds reduce the UV intensity and increase the instrument noise) or equipment failure account for missing days of data.

The activity of Mt Etna during July and August 1977 allowed the measurement of SO_2 output before, during, and after eruptive activity of the volcano. The SO_2 mass flow data are plotted

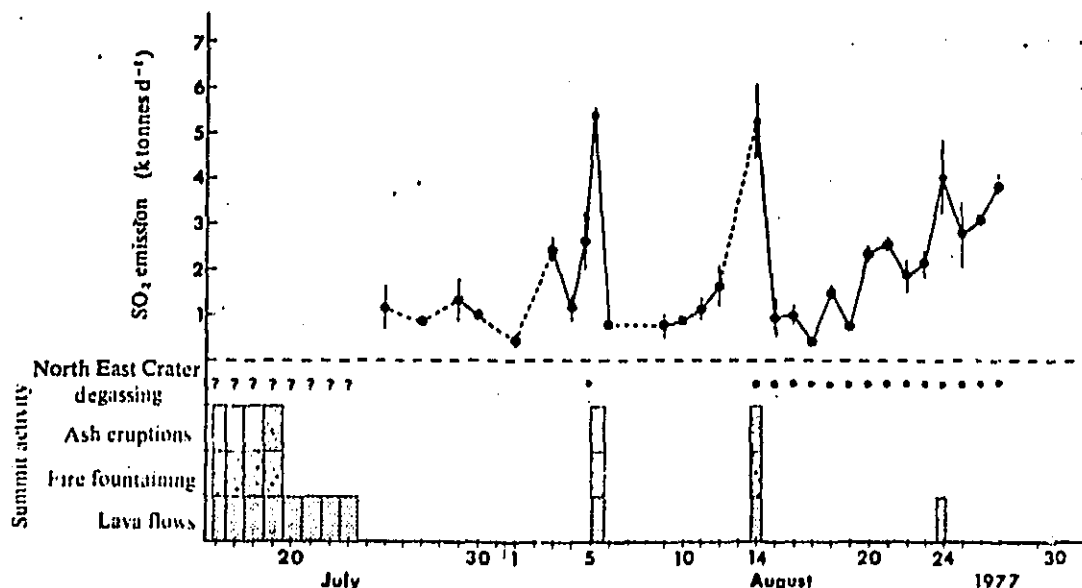


Fig. 3 SO_2 mass flow averages for the period of study. The dotted lines connecting the SO_2 data points are periods with missing days of data. The bars through each data point represent 1 standard deviation of the daily average. The bar graphs represent qualitative estimates of summit activity.

In Fig. 3. The SO_2 fluctuation curve is a plot of SO_2 mass flow (tonnes d^{-1}) versus time (16 July–28 August 1977). The bars through the points equal one standard deviation of the daily data. These should not be interpreted as error bars, but, rather an indication of the natural fluctuation of the volcano for a given day. The observed summit activity categories are meant only as qualitative estimates of the actual summit activity. The dotted lines connect intervals where there were missing days of data.

The data from 25 July to 1 August established a baseline level of $\sim 1,000$ tonnes d^{-1} for SO_2 mass flow during non-eruptive periods. The traverses made on the morning of 5 August showed SO_2 levels up to 3.3 times the 1,000 tonnes d^{-1} baseline value (1,830–3,330 tonnes d^{-1}). At 14.20 on the same day an eruption began in the North East Crater. Continued monitoring during the eruption showed that the SO_2 levels were above 5,000 tonnes d^{-1} .

By the morning of the 6 August, the activity had ceased and the SO_2 emission dropped to below the 1,000 tonnes d^{-1} baseline level. The mass flow apparently remained constant until the 10th when a gradual increase began which continued through the 12th. Due to poor weather, the SO_2 levels were not measured on the 13th. At 03.00 on the 14th, the third eruptive phase began with SO_2 levels during the day again above 5,000 tonnes d^{-1} . By the evening of the 14th, the eruption had ceased and SO_2 levels on the 15th returned to the 1,000 tonnes d^{-1} level.

SO_2 emissions from 15 to 24 August gradually increased to fairly high levels. The 4,000 tonnes d^{-1} average on the 24th was accompanied by a small lava flow within the North East Crater, but no explosive activity occurred as in the previous eruptions. Monitoring ended on 27 August, with the SO_2 levels still fairly high. However, no further activity was observed until December 1977.

The SO_2 mass flow values reported here are all minimum values. Three factors combine to reduce the measured SO_2 value. These factors are signal attenuation, plume opacity and loss of SO_2 by reaction to SO_4 . The COSPEC is a pathlength dependent device. As the distance between the plume and sensor increases, the measured SO_2 values decrease. This has been described by Moffat and Millán² in studies of powerplant plumes. Increasing plume opacity also tends to reduce the measured SO_2 values. This has also been documented in powerplant plume studies³. This factor is important to consider during eruptive activity when there is an increase in pyroclastic material in the plume. A third mechanism for SO_2 signal reduction is the reaction of SO_2 to SO_4 , in water droplets in the plume. The COSPEC sees only SO_2 therefore, SO_2 converted to SO_4 is effectively lost. The fact that these values are minimums does not reduce the validity of the SO_2 fluctuation curve since the mass flow averages were all obtained using the same technique, at equal distances from the vent, and at equal vertical distances from the plume.

It is evident that the increases in the SO_2 mass flow from Mt Etna could possibly be used as premonitory signs of impending activity. Two possible types of increases are suggested. First, the sharp increase such as before the 5 August eruption. Second, the gradual increase as exemplified by the periods 9–12 August, and 15–24 August.

The SO_2 mass flow variations correlate well with a model for the movement of magma within the conduit system at Etna proposed by Wadge⁴. He suggests that the eruptive pattern of Etna begins with filling of the conduit system. Activity is initiated by summit eruptions which are followed by flank eruptions. After the flank eruption drains the conduit system, the eruption ends and the cycle begins again. The SO_2 emission levels directly reflect the different levels of the magma.

In theory similar patterns should exist for all volcanoes. As the magma rises, SO_2 gas will be released in greater quantities. One should be able to monitor this increase. The absolute values for mass flow will vary from volcano to volcano, and possibly from eruption to eruption. The time fluctuation between observed

SO_2 increase and eruptive activity could be either compressed or extended.

Previous studies of condensates from high temperature fumaroles adjacent to main volcanic vents^{1,7} has long suggested that the SO_2 volume or S/Cl ratio increases before eruptive activity. The technique of remote sensing by correlation spectrometer provides a simpler and safer method for monitoring the SO_2 emission from the main vents of a volcano.

Several investigators have measured the SO_2 emission from various volcanoes^{8–12}. These data are in the same range as the data collected at Mt Etna, however, much more data are needed from individual volcanoes to determine the range of SO_2 emission and time period fluctuations. Given sufficient data, patterns might become well enough established to allow prediction of eruptions based on SO_2 fluctuations.

Funding for this project was from NASA grant NSG 5014, and from the Department of Earth Sciences of Dartmouth College. I thank Dr Richard Stoiber for his assistance with this project.

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Intra-plate deformation: a quantitative study of the faults activated by the 1978 Thessaloniki earthquakes

THE Thessaloniki region suffered from damaging seismic activity during the summer of 1978. During both major shocks that took place on the 24 May (M , 5.5) and 20 June (M , 6.5), manifestations of faulting could be observed in the epicentral areas. They showed that the continental crust is stretching out in this region. Measurement of slips on the active faults make it possible to compute the direction of traction (165° N) in the crust. These active faults show close kinematic similarities to previously neotectonically defined faults of Recent Quaternary age (after 400,000 yr) within the same region. Thus, study of Recent neotectonic faults often gives a correct prediction of the direction of possible slipping on faults which could be activated by earthquakes in the same region. We show here that a quantitative study of active and neotectonic faults demonstrates that in this intracontinental situation faulting deformation is satisfactorily explained with a model of continuous deformation.

The epicentral region is made up of a graben (Fig. 1) which demonstrates the presence of recent extensional tectonic activity in this area^{1,2}. An examination of the LANDSAT 1 satellite photographs (Fig. 1) indicates that this angular crank-shaped graben probably results mainly from sinistral wrench movement along NW–SE orientated fault zones. In addition opening occurs along normal faults of E–W to ENE–WSW directions. Similar movements have been observed, SW and SE of the Langadha Lake, on neotectonic faults which have a post Middle Pleistocene age³.

The faults that were formed during both 1978 earthquakes (Fig. 2) confirm this structural setting. Open cracks with an

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